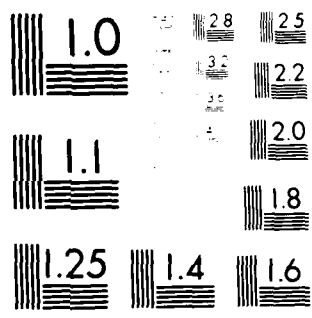


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(An apparatus is described that allows a continuous measurement of inspired and expired gas dew-point temperature for the calculation of water loss during ventilation (E_{res}). A rapid response dew-point temperature measurement method based on a small Peltier module. The compact structure with near zero system dead space minimizes potential errors inherent in many techniques used to measure E_{res} . A simple design and rugged construction permit the incorporation of the apparatus into many manual or personal computer controlled oxygen consumption systems. Collection of data may be done in a variety of ambient

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MODIFICATION OF OTIS-MCKERROW VALVE FOR MEASUREMENT OF
RESPIRATORY WATER LOSS

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Running head: water loss and respiration

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ABSTRACT

An apparatus is described that allows a continuous measurement of inspired and expired gas dew-point temperature for the calculation of water loss (E_{res}) during ventilation. A rapid response dew-point temperature measurement method is described which is based on a small Peltier module. The compact structure with near zero system dead space minimizes potential errors inherent in many techniques used to measure E_{res} . The simple design and rugged construction permit the incorporation of the apparatus into many manual or personal computer controlled oxygen consumption systems. Collection of data may be done in a variety of ambient temperatures, altitudes, and activity levels. There is also the potential for creating a portable system for field use.

key words: Respiratory water loss, dew-point temperature, and exercise

INTRODUCTION

Numerous techniques have been used to quantify respiratory water vapor loss (E_{res}). Among the measurement devices used are those which measure water content of the air (2,3,4,7), a combination of wet-bulb and dry-bulb thermometers (8), dielectric transducers (9), a mass spectrometer (6), and resistance hygrometers (8,9). These methods have created discrepancies between data collected and uncertainty involving the magnitude of the water lost. There appears to be disagreement as a result of inherent problems associated with these different techniques.

One possible source of error when measuring E_{res} is the dead space of a line system (3). The dead space is the part of the system which contains both inspired and expired gases. Water vapor from the expired gas condenses on the cool dead space walls. During inspiration the water vaporizes and enters the respiratory tract with the inspired gas. This condensed water vapor never reaches the measurement device, creating an error as great as 25% (3). A second factor known to affect respiratory water loss is the water vapor content of the inspired gas (7). A third source of error occurs in systems requiring the movement of gas samples to a distant sensor. Water condenses in the tube carrying the sample and does not reach the measurement device.

This condensation is particularly a problem at ambient temperatures below the expired gas dew point. The condensation can be minimized by heating all tubes carrying the gas sample. A fourth source of error could be attributed to the water vapor measurement devices used. Quick response resistance elements, such as the commonly used lithium chloride resistance hygrometer, have many limitations. These units are plagued with sudden calibration changes, frequent nonlinear responses, and hysteresis problems (9). Condensing devices, such as the one described by Caldwell et al. (3), involve the weighing of the complete collection system before and after a sampling period to determine the amount of water collected by the condensing coils. These condensing devices generate reproducible results, but applications are limited by the small number of data points produced.

The purpose of this paper is to describe an apparatus that allows a continuous measurement of inspired and expired gas dew-point temperatures for the calculation of water loss during ventilation. The apparatus can be used in a variety of ambient temperatures, altitudes, and activity levels.

Method of Construction

The data collection apparatus consists of a modified Otis-McKerrow valve (Warren E. Collins, inc. ; Braintree, Mass.), two automatic dew-point temperature sensors (5), two copper-constantan thermocouples, one Hewlett Packard power supply (model 6002A), one YSI recorder with thermister, and a specially constructed heating jacket. The general structure of the compact measurement apparatus and the collection system are shown in figures 1 and 2, respectively.

The dew-point sensor adapted for this application has previously been described in detail (5). The sensor consists of a Peltier module, having two electrically conductive plates on the top surface. These plates are separated by a narrow strip of non-conductive material. When the sensor is turned on the surface cools to the dew point, as determined by its water vapor content, temperature, and pressure of the gas in the surrounding atmosphere. As water vapor condenses on the surface, a vapor channel forms in the non-conductive strip, and a detector circuit senses such a drop in the resistance to current flow between the two conductive plates. The alteration in resistance switches the thermal module towards a heating mode. The condensed water evaporates, removes the conductive water channel, allowing an increase in the resistance to current flow between the two conductive plates, and switching the module once again to its cooling mode. The module surface temperature is measured as the

module continually completes this cycle. This temperature is the dew point temperature of the gas over the module surface, in compliance with the biophysical definition. (1,5)

We constructed the collection apparatus using the modified Otis-McKerrow valve (fig. 1). The basic structure of the valve creates a distinct separation of inspired, expired, and central chambers. An optional central chamber divider was used to split the central chamber in half, reducing the valve dead space volume to near zero. A 3.18mm hole was drilled in the top of the valve structure over the expired chamber. One dew-point temperature sensor was mounted on the exterior surface of the valve over the 3.18mm hole, using a silicone adhesive. A vacuum pump was connected to the dew-point sensor and used to draw a gas sample from the expired chamber, through the 3.18 mm hole, and on through the sensor. The vacuum flow rate passing the sensor was controlled at one liter per minute, using a calibrated flow meter. A thermocouple was placed in the center of the gas flow stream in both the inspired chamber entrance and expired chamber exit for the measurement of inspired and expired gas temperatures, respectively. A thermister was also attached to the wall of the expired chamber, so the chamber structure temperature could be monitored. A special jacket was constructed, using constantan wire ($3.28 \times 10^{-3} \text{ ohm} \cdot \text{mm}^{-1}$) and a piece of 6.35mm thick insulating material. The constantan wire was used to create a heating coil. The coil was attached to the sheet of insulating material, using aluminum tape. The jacket

was placed on the modified Otis-Mckerrow valve with the constantan coil against the valve and covered by the insulation material. The jacket heating coil was connected to the Hewlett Packard power supply and adjusted to maintain a chamber temperature of 36 to 38 °C.

The above described modified valve was then connected into a oxygen consumption evaluation system (fig. 2). The second dew-point temperature sensor with an attached vacuum pump was juxtaposed near the inspired gas intake of the system. The vacuum flow rate passed the sensors was controlled at one liter per minute.

***** Place figures 1 and 2 here. *****

Calculations: Water loss was then calculated using the following equation, derived from the ASHRAE Fundamentals Handbook (1).

$$E_{res} = \nabla_e \cdot (W_e / v_e) - \nabla_i \cdot (W_i / v_i), \text{ g} \cdot \text{min}^{-1}$$

where, ∇_e = minute volume of gas expired ($\text{l} \cdot \text{min}^{-1}$)

W_e = humidity ratio of gas expired: calculated, using gas percentage values obtained from expired gas ($\text{gH}_2\text{O/gdry gas}$)

v_e = specific volume of gas expired ($\text{l} \cdot \text{g}^{-1}$)

∇_i = minute volume of gas inspired ($\text{l} \cdot \text{min}^{-1}$)

W_i = humidity ratio of gas inspired: calculated, using gas

percentage values obtained from inspired gas
(gH₂O/gdry gas)

v_i = specific volume of gas inspired (l·g⁻¹)

A typical record is shown in figure 3. These data were collected from a healthy young adult male during a maximal exercise test (24°C, 760 torr).

***** Place figure 3 here. *****

This versatile apparatus can be used in a variety of ambient temperatures, altitudes, and activity levels. The near zero system dead space, and compact construction minimize the condensing problems created by other \dot{V}_{res} measurement systems. The rapid response Peltier module employed to measure dew-point temperature and the simplified structure of the apparatus makes it possible to incorporate it into many preexisting manual or personal computer controlled oxygen consumption systems. There is also the potential for creating a portable system for field use.

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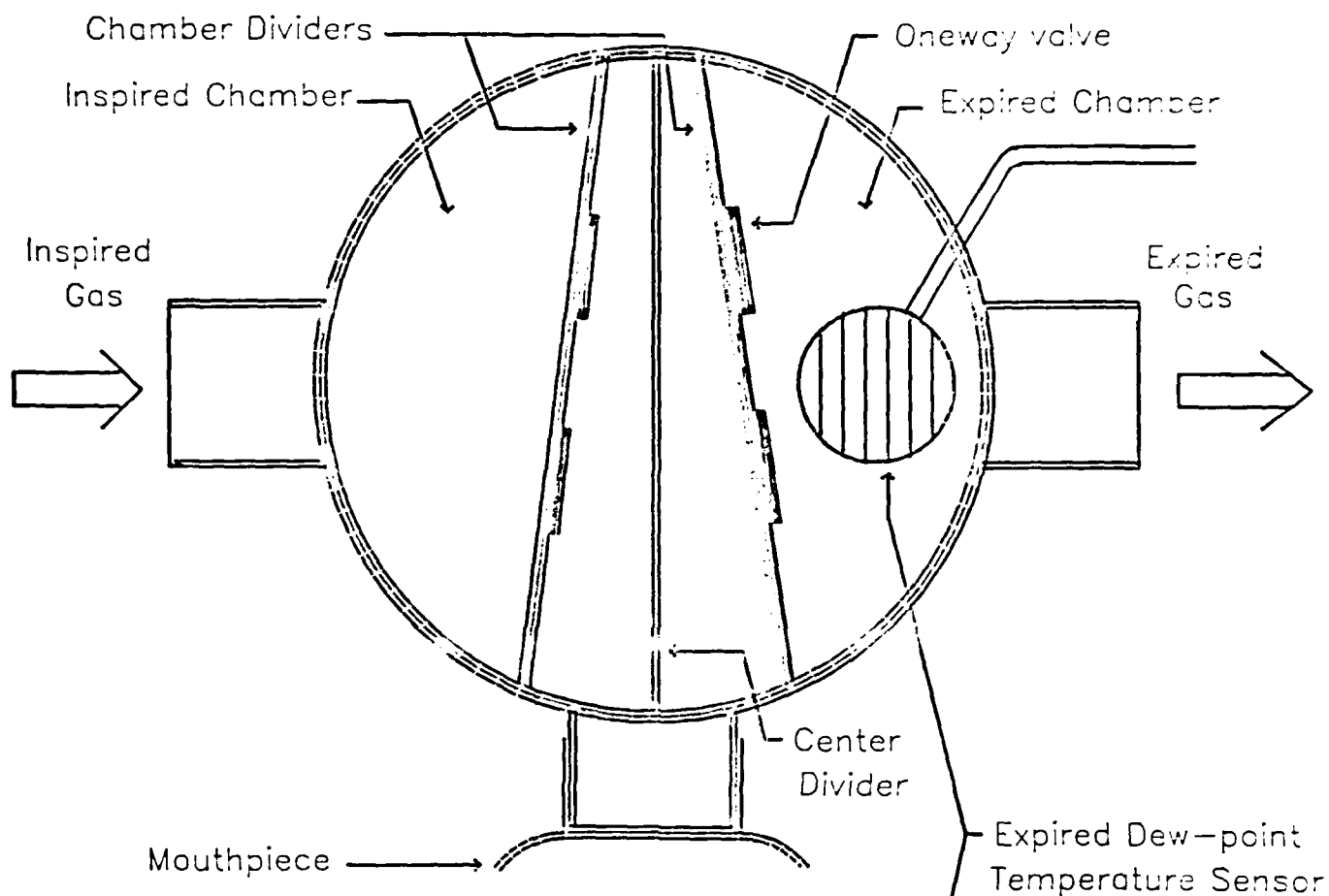
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Fig. 1

Collection Apparatus (Superior Aspect)



(Anterior: Cross Section)

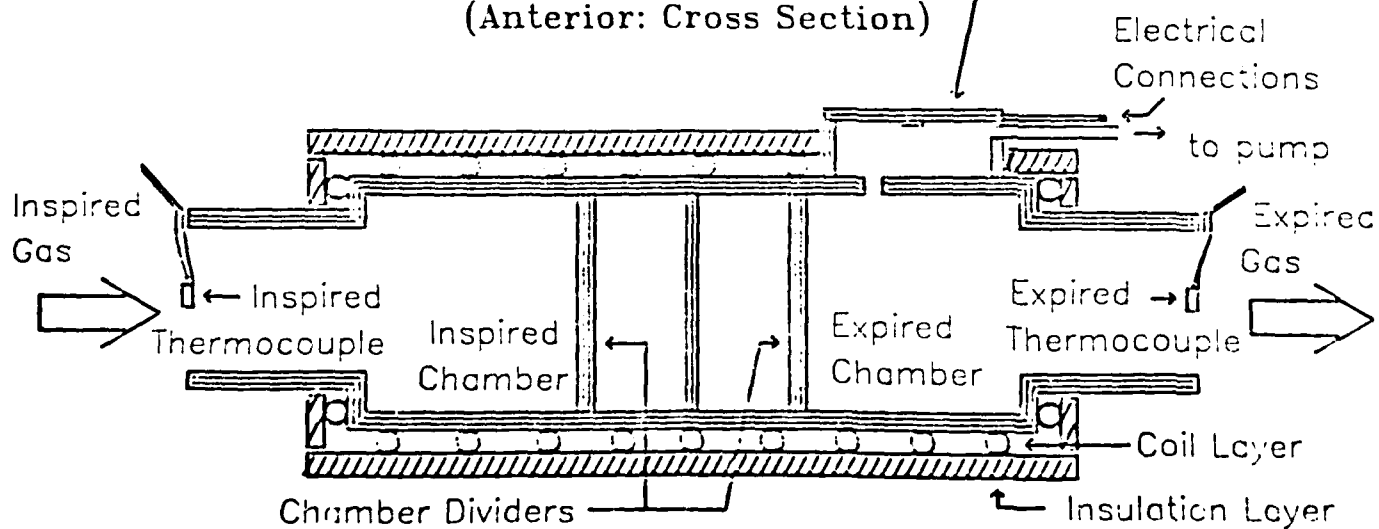


Fig 3

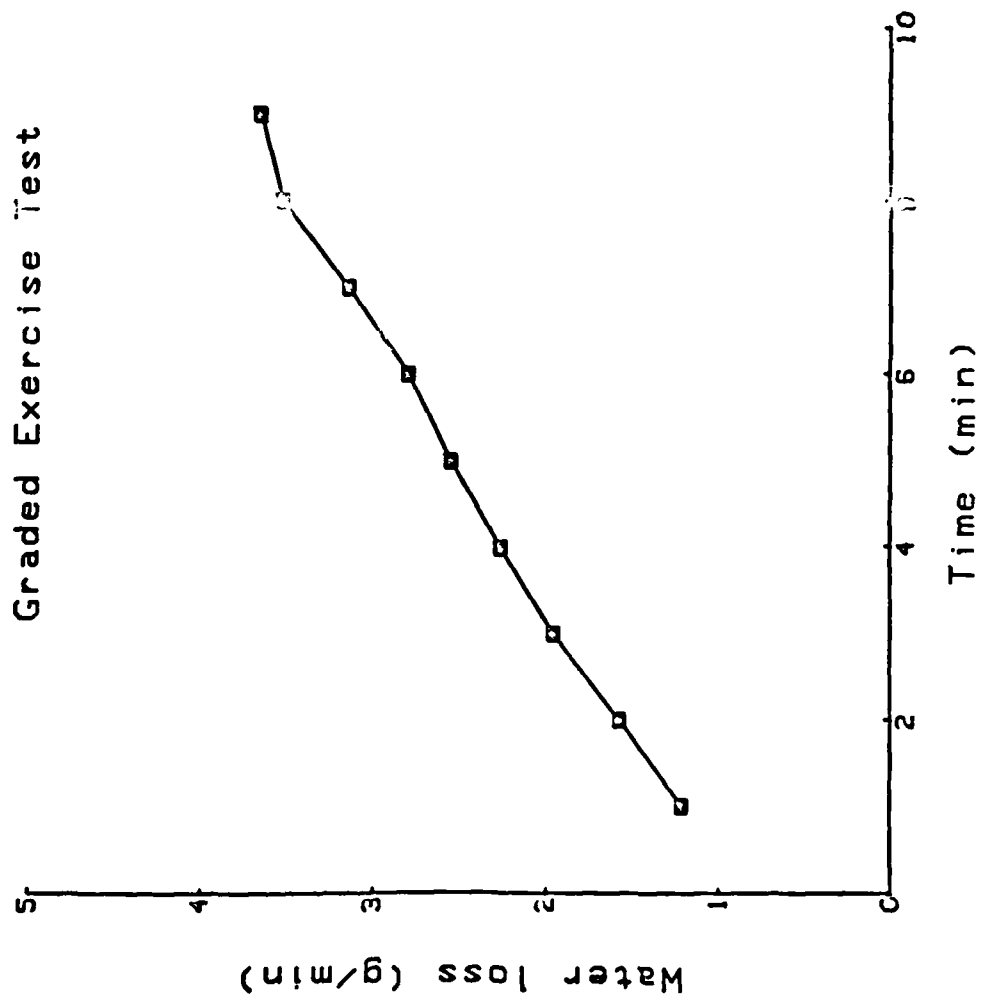


Figure legends

Figure 1.

Schematic showing the collection apparatus. Top: superior aspect; bottom: anterior cross section.

Figure 2.

Collection apparatus interposed onto automatic gas analysis system for measurement of $\dot{V}O_2$, $\dot{V}CO_2$, and E_{res} .

Figure 3.

Typical measurement of E_{res} ($g \cdot min^{-1}$) on a fit subject using the collection apparatus system in fig. 2 ($T_a = 24^\circ C$, $P_a = 760$ torr).